

Instrument and Method for Digital Image Stabilization

Field of the Invention

5 The invention relates to an arrangement and a method for
digitally stabilizing image recordings with a CCD sensor mounted
in a moving or flying carrier.

Background of the Invention

10 Stabilization systems known up to now operate in accordance
with the electromechanical principle with a cardanic suspension
of the sensor while driving the positioning motors via an
inertial sensor; or, CCD sensors are utilized when making aerial
image recordations without stabilization. Here, a migration of
the images must be accepted for a line sensor between the lines
or between frames with an area sensor. This image migration is
15 caused by disturbing movements of the carrier.

Generally, it is possible to provide image stabilization on
board or in a ground station. In the first case, there is an
on-line stabilization for display on a monitor and, in the second
case, there is an off-line image evaluation. As a rule, the
20 on-line stabilization is carried out. This takes place with area
sensors in camcorders. An on-line correction is carried out and
analog signal processing takes place.

For example, European patent publication 0,543,394 discloses
that, for an area sensor, the movements occurring at the time
25 point of the exposure are corrected on-line in a frequency range
of 1 to 12 Hz. The correction takes place via an optical
element. The correcting signals are determined via two sensors
which each measure the angular acceleration or the angular
velocity.

30 Furthermore, European patent publication 0,574,228 discloses

the determination of vibrations in the horizontal and vertical directions. Here, an on-line correction is made either via readdressing or reading out from a storage register at a lower frequency than for writing.

5 Finally, United States Patent 4,959,725 discloses a very complex circuit for correcting the video signal of an area sensor while performing an evaluation with accelerometers.

 However, all known solutions of the state of the art cannot be characterized as optimal with respect to their commercial
10 effectiveness because of the high cost associated therewith.

Summary of the Invention

 It is an object of the invention to provide an arrangement and a method for digital image stabilization with which the movement influences of a moving or flying carrier on the image
15 quality of a sensor are compensated at low cost. The sensor moves or flies with the carrier. More specifically, a correction of the effects of roll and pitch of the aerial image carriers having line sensors and area sensors is made possible with at
20 least pixel precision. This correction takes place digitally with large data quantities of > 6,000 pixels per line and therefore takes place off-line and is economical.

 The method of the invention is for digitally stabilizing an image recording with a CCD sensor, which is mounted in a moving or airborne carrier, for substantially eliminating unwanted
25 movement influences of flight movements of the carrier on the image quality of the image recorded by the CCD sensor. The method includes the steps of: detecting an image with the CCD sensor and outputting image data; detecting the flight movements of the carrier as angular data with an inertial sensor and the
30 inertial sensor being adapted to supply the angular data with a

time delay; and, correcting the image data in accordance with the detected angular data with the image data being time delayed by a time interval relative to the detected angular data.

Brief Description of the Drawings

5 The invention will now be described with reference to the drawings wherein:

FIG. 1 is a block circuit diagram of an arrangement of the invention for an on-line stabilization of image recordings; and,

FIG. 2 is a block circuit diagram of an arrangement for an
10 off-line stabilization of the image recordings.

Description of the Preferred Embodiments of the Invention

With the method and arrangement for digitally stabilizing an image in accordance with the invention, image stabilization can take place on board, that is, an on-line stabilization for
15 display on a monitor or in a fixed ground station, that is, an off-line image evaluation.

FIG. 1 shows a block circuit diagram of an on-line stabilization according to the invention and FIG. 2 shows a block circuit diagram of an off-line stabilization according to the
20 invention. Here, the movements of the carrier during flight are detected as angle data 11 with the aid of an inertial sensor 2 and are, together with the image data 10, intermediately stored or recorded on a data carrier 3 or 6.

For an image data correction, image lines are displaced by
25 corresponding angular increments transversely to the direction of flight for stabilization about the roll axis; whereas, a stabilization about the pitch axis takes place via an omission or a duplication of whole lines. The image data of neighboring pixels are interpolated in and transversely to the flight
30 direction for a stabilization accuracy in the subpixel range.

The inertial sensor 2 detects the flying movements and can be a so-called "strap-down sensor". For this sensor, the stabilization result is essentially dependent upon the scale accuracy and the bandwidth of the sensor. The inertial sensor 2
5 has a finite bandwidth which is typically 100 Hz and therefore supplies the detected angular data 11 with a time delay. For this reason, its transmitting performance at low frequencies can be approached by a dead time element (linear phase, that is, phase lag proportional to frequency).

10 A dynamically calibrated gyro (DAK) is very well suited as an inertial sensor 2. With such devices, scale errors to 0.1% and bandwidths up to 100 Hz are achievable.

For an exemplary embodiment of a dynamically calibrated gyro (DAK), which is used as an inertial sensor 2, the pixel size
15 of the sensor (dx) was 12 μm , the bandwidth of the objective (f) was 60 mm; the angular expansion of the sensor ($DAS = dx/f$) was 0.2 mrad and the line frequency was minimally 200 Hz and maximally 2,500 Hz. Sinusoidally-shaped disturbance excitations in the region of $10^\circ/0.2 \text{ Hz}$ to $0.2^\circ/10 \text{ Hz}$ have rotational
20 increments of $12.5^\circ/\text{sec} = 220 \text{ mrad/sec}$.

For an exposure time of 0.4 ms, an image blurring of 0.09 mrad results which corresponds to 0.5 pixels; whereas, for an exposure time of 5 ms, an image blurring of 1.1 mrad results which corresponds to 5.5 pixels. Accordingly, an image
25 blurring over several pixels must be accepted at low line frequencies which can no longer be corrected by the subsequent stabilization.

A total error or the quadratic sum of the residual error of the digital stabilization and the image blurring amounts
30 to 0.22 mrad in dependence upon the line frequency or line

rate (LR) for LR = 2,500 Hz and to 1.12 mrad for LR = 200 Hz. In this way, the following results for the stabilization factor:

		Stabilization Factor for
Disturbance Excitation:		LR = 2,500 Hz (200 Hz)
5	10°/0.2 Hz	792 (155)
	0.2°/10 Hz	16 (3)

The computer simulation of a dynamically calibrated gyro (DAK) having a bandwidth of 100 Hz and a scale error of 0.1% has shown that the stabilization error of the corrected image is ≤ 0.2 mrad (zero peak) for sinusoidally-shaped disturbance excitations in the range from 10°/0.2 Hz to 0.2°/10 Hz.

A digital image stabilization is therefore purposeful when the frequencies of the disturbance excitation are so low that no intense "blurring" occurs during the exposure time. The use of stabilization can be evaluated by the stabilization factor which is the amplitude ratio of disturbance excitation and residual image movement.

Especially even non-stabilized sensors can be economically expanded with an arrangement for digital image stabilization via corresponding modules and therefore made more valuable.

A digital image stabilization according to the invention can take place as an on-line stabilization (FIG. 1) for display on a monitor 5 or as an off-line stabilization in a fixed ground station. In the on-line stabilization, an inertial sensor 2 is provided on board and a device for intermediate storage 3 of image data as well as a device for image data correction 4. In the off-line stabilization, an inertial sensor 2 and an additional recording device 6 for angular sensor signals (angular data) are provided on board and, in the ground station, a device 4' is provided for carrying out an image correction in

accordance with registered or recorded angular sensor signals (angle data).

The arrangement and method for digital image stabilization use especially the concept of storing or time delaying the image data. For image correction, the image data are delayed relative to the recorded angle data by a time delay interval which considers the time delay caused by the inertial sensor as well as by scanning and computer time.

For the on-line stabilization (on board the carrier) as shown in FIG. 1, a detection of image data 10 takes place via a CCD sensor. The CCD sensor is utilized in a moving or flying carrier. These image data 10 are intermediately stored in a device 3 and are outputted as time-delayed image data 10' to a device for image correction 4. Additionally, the device for image data correction 4 receives data from an inertial sensor 2 (angle data) which reflect the movements of the carrier. The device for image data correction 4 generates a stabilized image 13 from the delayed image data 10' and the angle data 11 and this stabilized image is displayed on a monitor 5 which likewise is disposed on board the carrier.

In the off-line stabilization as shown in FIG. 2, a detection of the image data 10 takes place via a CCD sensor 2 provided on board a moving or flying carrier. Furthermore, an inertial sensor 2 is configured on board the carrier which detects the flying movements of the carrier and outputs corresponding angular data 11. These angle data 11, together with the image data 10, are recorded in a recording device 6. For off-line evaluation and image data correction, the recorded image data and angle data 12 are outputted to a device for image data correction 4' in a ground station. This device for image

data correction 4' delays the image data relative to the recorded angle data by a time interval which considers the time delay caused by the inertial sensor as well as by scanning and computation time.

5 With the measures explained above, the problematic of unwanted movement effects of a moving or flying carrier on the image quality of a sensor (which moves with or flies with the carrier) is solved in a very economical manner via digital stabilization.

10 A performance increase is achieved by an integration of the arrangement and method according to the invention into electrooptical sensor systems.

15 It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.